

# Tropospheric Airborne Meteorological Data and Reporting (TAMDAR) Icing Sensor Performance during the 2003/2004 Alliance Icing Research Study (AIRS II)

John J. Murray\*, Louis A. Nguyen†, Taumi. S. Daniels‡, Patrick Minnis§, Phillip R. Schaffner\*\*, Melinda F. Cagle††,  
Michele L. Nordeen‡‡

*NASA Langley Research Center, Hampton, Virginia, 23681*

Cory A. Wolff§§

*National Center for Atmospheric Research, Boulder, Colorado, 80301*

Mark V. Anderson\*\*\*, Daniel J. Mulally†††, Kristopher R. Jensen†††  
*AirDat, LLC., Evergreen, Colorado, 80439*

Cedric A. Grainger§§§ and David J. Delene\*\*\*\*

*University of North Dakota, Grand Forks, North Dakota, 58202*

**NASA Langley Research Center and its research partners from the University of North Dakota (UND) and the National Center for Atmospheric Research (NCAR) participated in the AIRS II campaign from November 17 to December 17, 2003. AIRS II provided the opportunity to compare TAMDAR in situ in-flight icing condition assessments with in situ data from the UND Citation II aircraft's Rosemont system. TAMDAR is designed to provide a general warning of ice accretion and to report it directly into the Meteorological Data Communications and Reporting System (MDCRS). In addition to evaluating TAMDAR with microphysical data obtained by the Citation II, this study also compares these data to the NWS operational in-flight icing Current Icing Potential (CIP) graphic product and with the NASA Advanced Satellite Aviation-weather Products (ASAP) Icing Severity product. The CIP and ASAP graphics are also examined in this study to provide a context for the Citation II's sorties in AIRS II.**

## I. INTRODUCTION

THE second Alliance Icing Research Study (AIRS II) concerned potential and ambient weather that affected in-flight icing conditions in the vicinity of the Mirabel Airport near Montreal, Quebec during the winter of 2003 to 2004. It was conducted by the bi-national Aircraft Icing Research Alliance under a cooperative agreement between the National Research Council of Canada and NASA and included the participation of NOAA, the FAA and government and university research laboratories throughout the U.S. and Canada. AIRS II was conducted to develop techniques to remotely detect, diagnose and forecast hazardous winter conditions at airports and to improve weather forecasts of aircraft icing conditions, the characterization of the aircraft icing environment and the overall understanding of the icing process and its effect on aircraft<sup>1</sup>. Data was collected by ground, airborne and space-based

\* Atmospheric Scientist, Chemistry and Dynamics Branch, NASA, MS-401B, Hampton, VA 23681

† Atmospheric Scientist, Climate Science Branch, NASA, MS-420, Hampton, VA 23681

‡ Project Manager, Electromagnetics and Sensors Branch, NASA, MS-473, Hampton, VA 23681

§ Atmospheric Scientist, Climate Science Branch, NASA, MS-420, Hampton, VA 23681

\*\* Sensor Engineer, Electromagnetics and Sensors Branch, NASA, MS-473, Hampton, VA 23681

†† Atmospheric Scientist, Climate Science Branch, NASA, MS-401A, Hampton, VA 23681

††† Research Scientist, Analytical Services and Materials, Inc., 1 Enterprise Parkway, Hampton, VA 23666

§§ Atmospheric Scientist, NCAR Foothills Laboratory 4, 3450 Mitchell lane, Boulder, CO 80301

\*\*\* President, Engineering Research and Development, 30746-410 Bryant Dr., Evergreen, CO, 80439

††† Vice President, Engineering Research and Development, 30746-410 Bryant Dr., Evergreen, CO, 80439

††† Engineer, Engineering Research and Development, 30746-410 Bryant Dr., Evergreen, CO, 80439

§§§ Professor, Department of Atmospheric Sciences, UND, Grand Forks, ND, 58202

\*\*\*\* Assistant Professor, Department of Atmospheric Sciences, UND, Grand Forks, ND, 58202

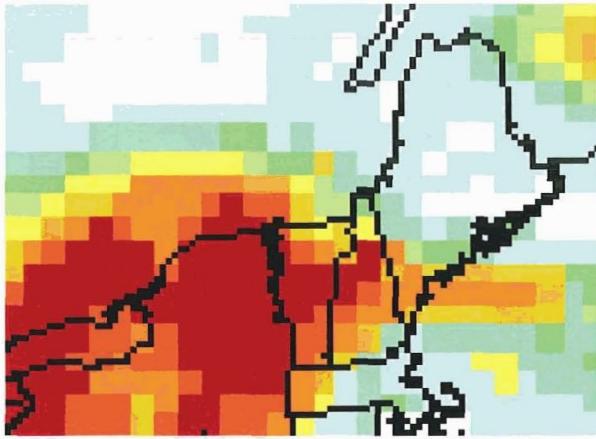


Figure 9 . CIP Product VT 1900UTC 28Nov03

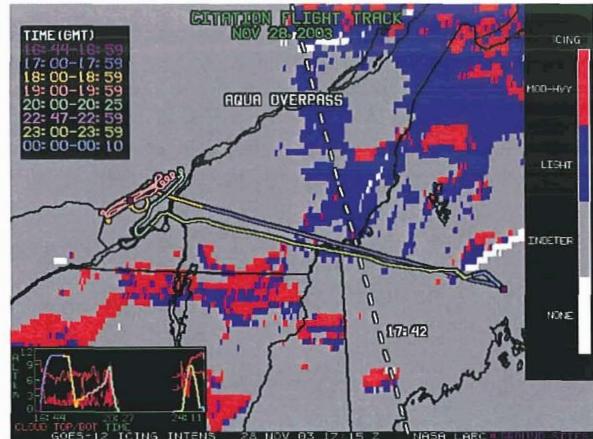


Figure 10. NASA Icing Severity VT 1715UTC 28Nov03

The Current Icing Potential Product for 12,000 feet, the level of maximum icing potential is compared to the NASA Icing severity index which is obscured over much of the icing region by multi-layered clouds. Areas that are amenable to analysis on the satellite product appear to correspond well with the CIP.

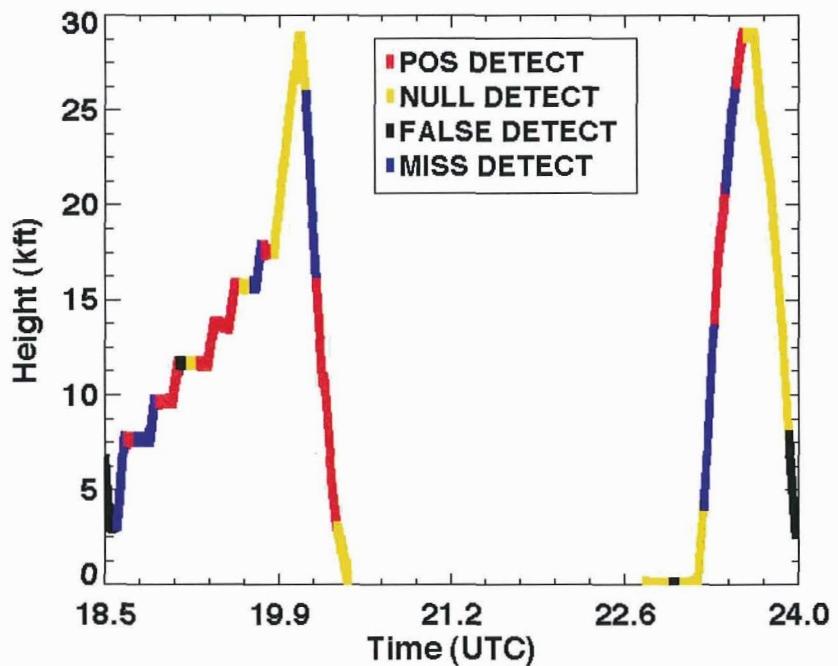


Figure 11. TAMDAR/Rosemont Comparison, November 28.

A comparison of TAMDAR icing detection on November 28 with the UND Citation's instrumentation is shown in figure 11. Ice was first encountered by the Rosemont system at approximately 18:300 UTC. Following initial detection, 41 analysis increments were examined. For these increments, TAMDAR and Rosemont's combined agreement for positive and null detections is 68%. Seven missed detections and 6 false detections were noted constituting a 32% error rate for this case.

### E. November 30, 2003 Case Study

The Citation took off from Bangor at 1624 UTC, arriving over Mirabel at FL350 at about 1730 as shown in Fig. 11. A spiral descent was made over the runway intersection down to FL40. Clouds were not encountered until about FL72, where there was a layer about 1000 ft thick. The lower clouds had tops slightly above FL40, but variable. Several measurement passes were made along the runway at FL40 going in and out of cloud along the way. In cloud, the Citation encountered light to moderate rime ice and liquid water contents of 0.1 to 0.4 g/m<sup>3</sup>. This was followed by a missed approach over the runway from FL40. The cloud extended down to slightly below FL20. This was followed by passes at FL70 going west to east and missed approaches from FL70 over the runway going east to west. This profile was carried out several times. In general, the liquid water content was higher in the upper cloud layer, with larger mean values of the droplet sizes. There were a few ice crystals in both layers, but the clouds were composed primarily of water droplets. The clouds were well characterized by the measurements in the horizontal as well as the vertical.

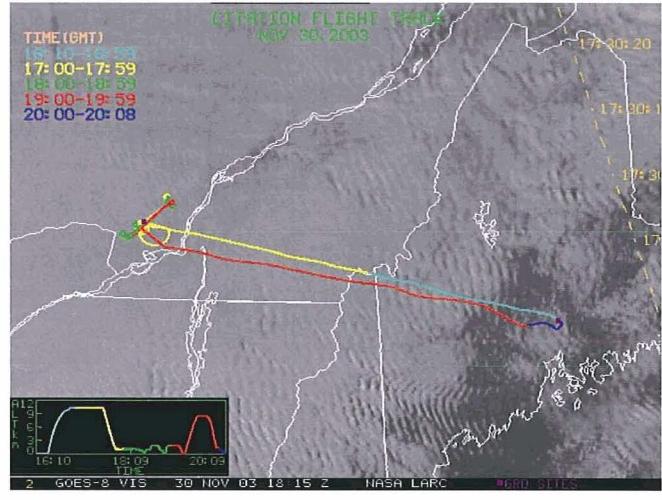


Figure 12. Citation II November 30, 2003 AIRS II Sortie

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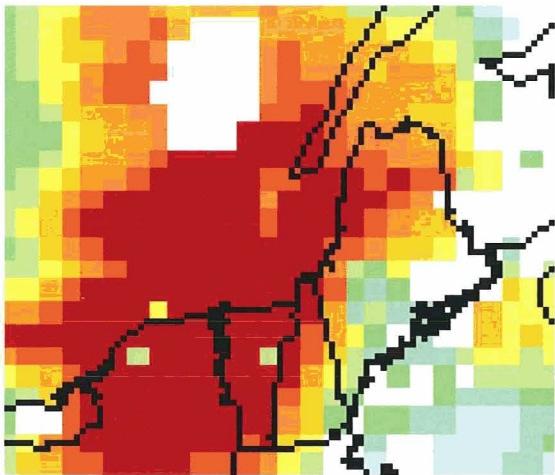


Figure 13 . CIP Product VT 1900UTC 30Nov03

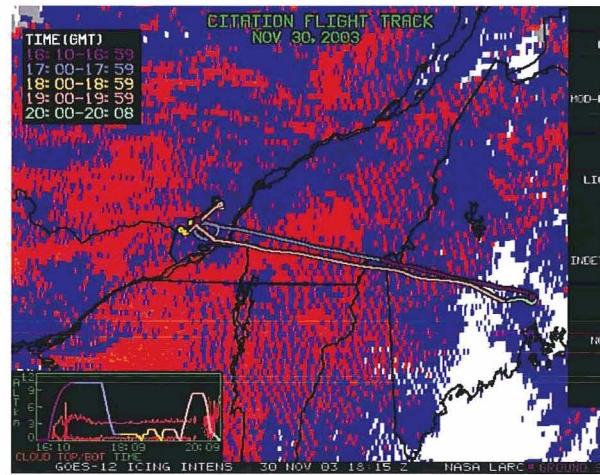


Figure 14. NASA Icing Severity VT 1715UTC 30Nov03

The Current Icing Potential product for November 30, 2003 shown in figure 13 indicates a large area of high icing potential at 4000 feet in altitude. The corresponding NASA Icing Severity Index depicted in figure 14 agrees very well with the CIP for areas of high icing potential as indicated earlier and for areas of little or no icing potential such as can be seen over southern Maine. Effective cloud heights for both tops and bases that comprise the Icing Severity Index are plotted in Figure 15. This case was examined extensively in earlier work by Nguyen et al.<sup>8</sup>. The satellite retrievals indicated that light icing conditions existed during the first hour of flight where the Citation climbed and maintained an altitude above 30,000 feet during the transit from Bangor to Mirabel. Satellite-derived cloud bases and tops were estimated at approximately 1,500 and 10,000 feet. As the Citation made a spiral descent over the Mirabel runway, the Rosemount started detecting icing at 10,000 feet while the TAMDAR picked up icing at 6500 feet during the descent.

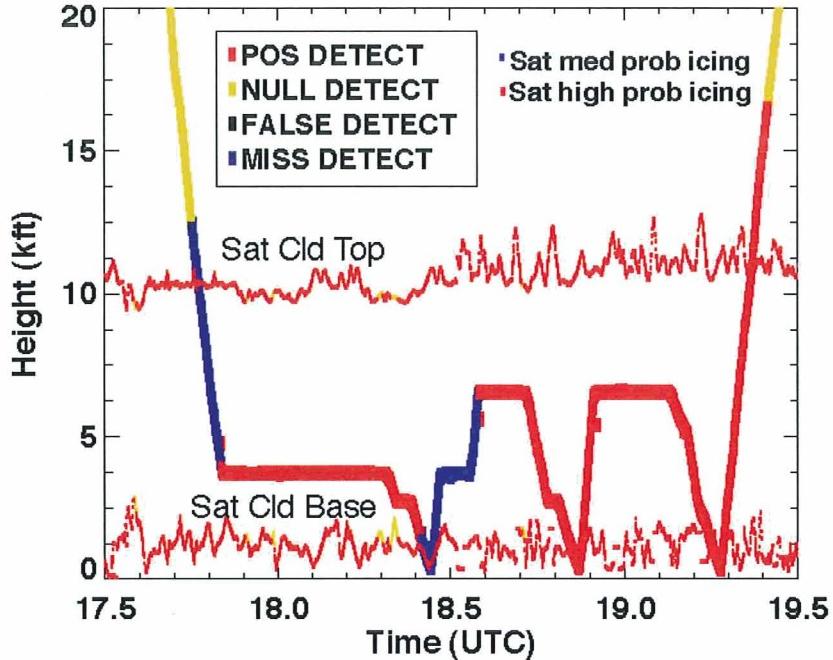


Figure 15. TAMDAR/Rosemont Comparison, November 30.

A comparison of TAMDAR icing detection on November 30 with the UND Citation's instrumentation is also shown in figure 15. Very good correspondence between TAMDAR and Citation instrumentation for the detection of icing and null conditions is indicated for this case. Ice was first encountered by the Rosemont system at approximately 16:00 UTC. Thereafter, 48 analysis increments were examined. For these increments, TAMDAR and Rosemont's combined agreement for positive and null detections is 94%. Three missed detections occurred constituting a 6% error rate over the 48 sampling increments. No false alarms were observed.

#### E. December 11, 2003 Case Study

The Citation took off from Bangor at 1519Z, and arrived over Mirabel at 35,000 ft at 1614Z. A spiral descent site encountered cloud tops at 29,500 ft. The clouds at the high elevations were composed of ice crystals. There were several layers of cloud during the descent, but no liquid water was encountered until 11,000 ft, where there were small patches of relatively low (less than 0.2 g/m<sup>3</sup>). The sounding went down to 3,000 ft ( $T=+2.6C$ ), where there were precipitation sized water drops. The super-cooled water was between about 11,000 and 8,000 ft. Horizontal transects were made in 1,000 ft intervals parallel to runway 06/24 between these altitudes and a missed approach was made from 11,000 ft down to 250 ft. The citation then climbed to 29,000 ft to within an estimated 500 ft of cloud top at 1838Z. The aircraft landed in Montreal at 1858Z.

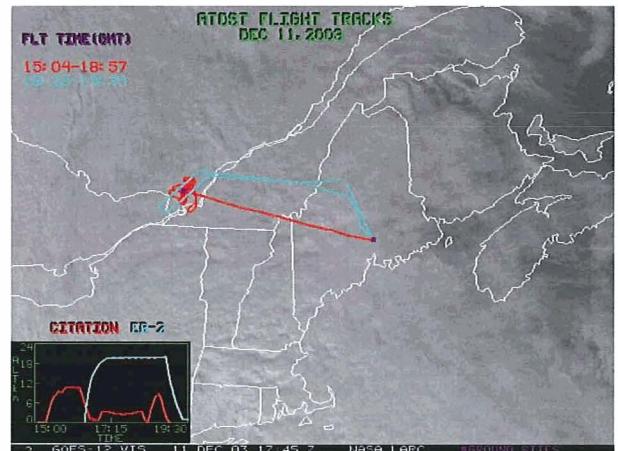


Figure 16. Citation II December 11, 2003 AIRS II Sortie

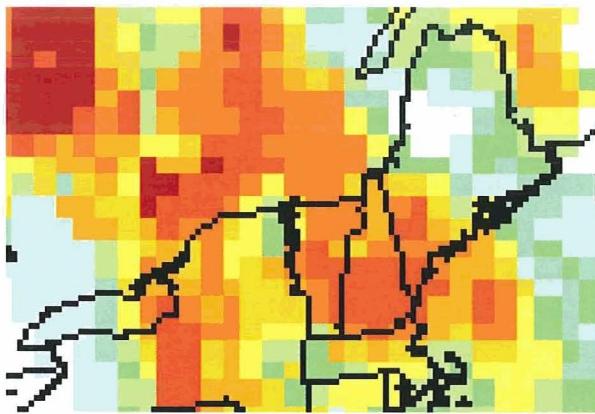


Figure 17 . CIP Product VT 1900UTC 11Dec03

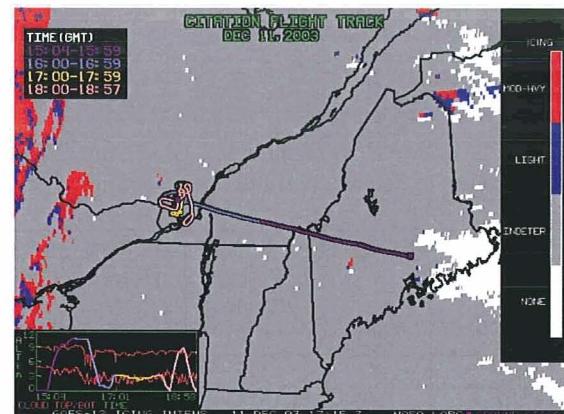


Figure 18. NASA Icing Severity VT 1715UTC 11Dec03

The Current Icing Potential Product for 10,000 feet, the level of maximum icing potential is compared to the NASA Icing severity index which is obscured over most of the icing region by multi-layered clouds.

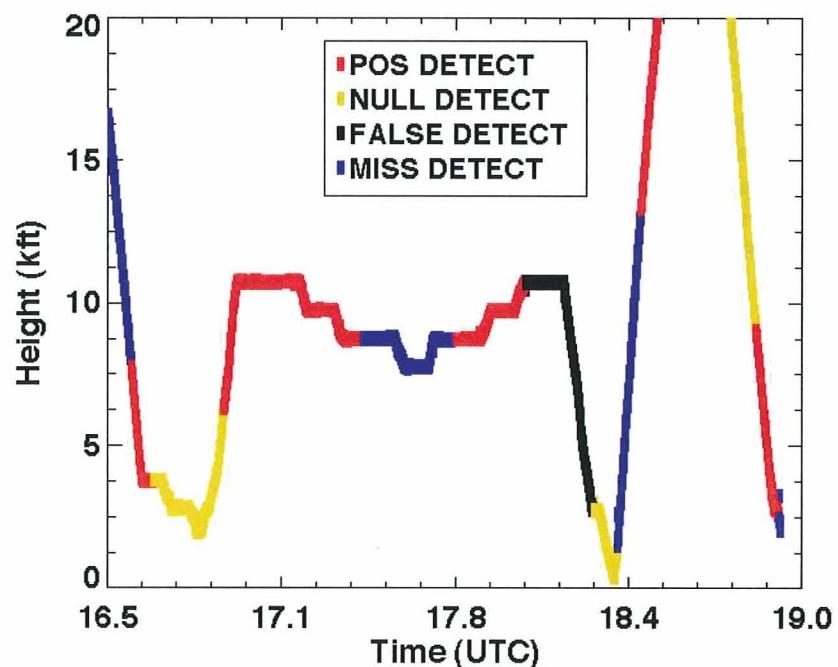


Figure 19. TAMDAR/Rosemont Comparison, December 11.

A comparison of TAMDAR icing detection on December 11 with the UND Citation's instrumentation is shown in figure 19. Ice was first encountered by the Rosemont system at approximately 16:300 UTC. Following initial detection, 31 analysis increments were examined. For these increments, TAMDAR and Rosemont's combined agreement for positive and null detections is 68%. Seven missed detections and 3 false detections were noted constituting a 10% error rate for this case.

#### IV. TEST RESULTS AND DISCUSSION

##### A. TAMDAR Sensor Performance.

This study provides the first quantitative assessment of TAMDAR icing detection capabilities for a focused in-flight icing campaign. The analysis and comparison of the data collected onboard the UND Citation II over Mirabel, Quebec during the AIRS II flight campaign in November and December 2003 indicates that the TAMDAR sensor will detect light to moderate in-flight icing at flight levels typically flown by regional commercial aircraft and

general aviation. Severe icing conditions were not encountered. Using Rosemont as ground truth, in-flight icing detection data from the TAMDAR was evaluated to determine positive, null, missed and false detection rates. Overall, for the four cases studied, 132 sample increments were evaluated yielding a combined agreement rate between TAMDAR and Rosemont of 77% and a combined error rate of 23%. The bottom row of figure 20 is germane. TAMDAR's icing detection capability as compared to the Rosemont ice detector indicates that as a general indicator if in-flight icing conditions TAMDAR is effective. The performance statistics warrant further investigation to determine if there is a situational or methodological bias inherent in the data or the analysis.

Dates	Samples	# Pos. Detect (T+/R+)	% Pos. Detect (T+/R+)	# Null Detect (T-/R-)	% Null Detect (T-/R-)	# Miss Detect (T-/R+)	% Miss Detect (T-/R+)	# False Detect (T+/R-)	% False Detect (T+/R-)
11/24	12	6	50	1	8	5	42	0	0
11/28	41	12	29	16	39	7	17	6	15
11/30	48	17	35	28	59	3	6	0	0
12/11	31	12	39	9	29	7	22	3	10
Combined	132	47	36	54	41	22	16	9	7

**Figure 20. Comparison of TAMDAR (T) and Rosemont (R) in Cessna Citation II Icing Missions**

## B. Evaluation of Regional Icing Products.

This study indicates that the both the CIP and GOES products are generally validated by the two independent in situ icing detection systems installed on the Cessna Citation II. Research on the enhancement of the more broadly based CIP with the NASA Icing Severity Index is being conducted jointly by NCAR and the NASA Langley Research Center. The extension of the NASA products to produce multi-level indices is also occurring. Since the GOES imager views only the tops of the clouds directly, the occurrence of icing below cloud top must be derived using the retrieved microphysics combined with additional information such as Rapid Update Cycle RUC model output. Additional analyses using a three-dimensional estimate of aircraft icing from the satellites<sup>9</sup> should provide for a more direct comparison between the satellite, the CIP and aircraft.

## V. ACKNOWLEDGMENTS

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## VI. REFERENCES

<sup>1</sup>Hallet, J., Isaac, G., Politovich, M., Marcotte, D., Reehorst, A., Ryerson, C., "AIRS II Science Plan," [cited July 7, 2003], URL: [http://www.airs-icing.org/AIRS\\_II/2003-07-07\\_AIRS\\_II\\_Science\\_Plan.pdf](http://www.airs-icing.org/AIRS_II/2003-07-07_AIRS_II_Science_Plan.pdf).

<sup>2</sup>Daniels, T. S., Tsoucalas, G., Anderson, M., Mulally, D., Moninger, W., Mamrosh, R., "Tropospheric Airborne Meteorological Data Reporting (TAMDAR) Sensor Development," *11th Conf. on Aviation, Range, and Aerospace Meteorology*, Hyannis, MA, American Meteorological Society.

<sup>3</sup>Murray, J. J., Schaffner, P.R., Minnis, P., Nguyen, L., Delnore, V.E., Daniels, T.S., Grainger, C.A., Delene, D. Wolff, C.A., TAMDAR icing sensor performance during the 2003 Alliance Icing Research Study (AIRS II).", *11th Conf. on Aviation, Range, and Aerospace Meteorology*, Hyannis, MA, American Meteorological Society.

<sup>4</sup>Daniels, T. S., "Tropospheric Airborne Meteorological Data Reporting (TAMDAR Sensor Development," 2002-02-153, *SAE General Aviation Technology Conference and Exposition*, April 16-18, 2002, Wichita, KS.

<sup>5</sup>Delene, D.J., University of North Dakota, Aviation Science Program, Cessna Citation II webpage, <http://www.atmos.und.edu/instrumentation.htm>.

<sup>6</sup>Bernstein, B.C., McDonough, F., Politovich, M.P., Brown, B.G., Ratvasky, T.P., Miller, D.R., Wolff, C.A., and Cunning, G.C., 2004: Current Icing Potential (CIP): Algorithm description and comparison with aircraft observations. Submitted to Journal of Applied Meteorology.

<sup>7</sup>Minnis, P. "Real-time cloud, radiation, and aircraft icing parameters from GOES over the USA". *13<sup>th</sup> AMS Conference on Satellite Oceanography and Meteorology*, Norfolk, VA, September 20-24, 2004.

<sup>8</sup>Nguyen, L., Minnis, P., Spangenberg, D.A., Nordeen, M.L., Palikonda, R., Khaiyer, M.M., Gultepe, I., and Reehorst, A.L., "Comparison of satellite and aircraft measurements of cloud microphysical properties in icing conditions during ATREC/AIRS-II.", *11th Conf. on Aviation, Range, and Aerospace Meteorology*, Hyannis, MA, American Meteorological Society.

<sup>9</sup> Minnis, P., Nguyen, L., Palikonda, R., Spangenberg, D.A., Ayers, J.K., Yi, Y., Nordeen, M.L., and Wolff, C.A., "Toward a three-dimensional near-real time cloud product for aviation safety and weather diagnoses.", *11th Conf. on Aviation, Range, and Aerospace Meteorology*, Hyannis, MA, American Meteorological Society.

